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TWO-DIMENSIONAL GIMBALED SCANNING ACTUATOR WITH VERTICAL ELECTROSTATIC COMB-DRIVE FOR ACTUATION AND/OR SENSING

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to the following copending U.S. provisional applications, which are herein incorporated by reference: Provisional Application 60/191,987 "Two-Dimensional Scanning Actuator with Vertical Electrostatic Comb Drive Actuation and/or Sensing" of Behrang Behin, Michael J. Daneman, Meng H. Kiang, Kam Y. Lau, and Satinderpall Pannu; Provisional Application 60/191,856, "Self-Aligned Comb-Drive Actuators" of Behrang Behin and Satinderpall Pannu; Provisional Application 60/192,097 "Multi-Layer, Self-Aligned Vertical Comb-Drive Electrostatic Actuators and Fabrication Methods" of Behrang Behin and Satinderpall Pannu.

FIELD OF THE INVENTION

This invention relates generally to microactuators. More particularly, it relates to two-dimensional gimbaled scanning actuators with vertical comb-drives for actuation and/or sensing.

BACKGROUND ART

Microelectromechanical system (MEMS) fabricated using silicon integrated circuit processing techniques have been developed for a wide variety of applications that require actuation and/or sensing of microstructures. The electrostatic comb-drive structure has become an integrated component in many of these MEMS device. A vertical comb-drive device can be used to generate an actuating force on a suspended structure as a bias voltage is applied. This force can be used to actuate microstructures out of the plane in which they were made.

Electrostatically actuated gimbaled two-dimensional actuators have previously employed an electrostatic gap-actuator design shown in FIG. 1. As shown in FIG. 1, a gimbaled electrostatic-gap actuator **100** consists of a base **102**, an outer frame **104**, and an inner part **108**. The outer frame **104** is attached to a base **102** by a first pair of torsional flexures **106**. The inner part **108** is attached to the outer frame **104** by a second pair of torsional flexures **110** positioned at a perpendicular angle relative to the first pair of torsional flexures **106**. The gimbaled electrostatic-gap actuator **100** is suspended over a set of electrodes **112**, and the angle of the gimbaled electrostatic-gap actuator **100** is adjusted by applying a voltage difference between the electrodes **112** and the suspended actuator **100**. The gimbaled electrostatic-gap actuator requires a high voltage to achieve a significant angular deflection. Furthermore, the angle versus applied voltage characteristics of this structure are very nonlinear because the gap between the electrodes **112** and the suspended actuator **100** changes as the angle of the actuator is varied, and the electrostatic force between the electrodes **112** and the suspended actuator **100** has a nonlinear dependence on the gap. In fact, gap-closing actuators with linear restoring springs typically have a 'snap-in' instability point at approximately one-third of the full range of motion of the actuator. In addition, the two perpendicular axes of rotation can not be independently controlled since adjusting one axis changes the electrostatic gap associated with the other. This cross-axis dependence makes control of such structures difficult.

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In the electrostatic gap-actuator structure of the prior art, the capacitance between the electrodes **112** and the suspended actuator **100** can be measured in order to monitor the position of the actuator. However, since the gap between the electrodes **112** and the suspended actuator **100** must be fairly large in order to allow for a large angular deflection, this capacitance is very small, and the accuracy of the capacitive measurement is very poor.

Vertical electrostatic comb-drive actuators have been employed to make one-dimensional rotational scanners. Electrostatic comb-drive actuators allow for exertion of a greater force over a large range by increasing the effective overall capacitive gap area. Furthermore, they allow for a more linear angle versus applied voltage relationship since the capacitive overlap area between the opposing electrodes depends almost linearly on the angle of the actuator, and the gap between the opposing electrodes remains fairly constant over the entire actuation range. Vertical electrostatic comb-drive actuators, which are shown in FIGS. 2A-B, have been used to produce one dimensional rotating mirror structures with significantly lower actuation voltages than required for electrostatic gap actuators as described in FIG. 1. FIG. 2A is a plan view of one-dimensional vertical comb-drive actuator **200** without applied voltage. The device **200** includes a base **202** and a mirror **204** attached to the base **202** by a pair of torsional flexures **206**. Two vertical electrostatic comb-drive actuators containing movable comb fingers **208** and fixed comb fingers **210** are fixed to the base **202** and the mirror **204** such that the degree of engagement, or the overlap area, between the interdigitated comb fingers depends on the angle between the base **202** and the mirror **204**. FIG. 2B is a plan view of the device illustrated in FIG. 2A with an applied voltage. As shown in FIG. 2B, applying a voltage to the actuators attracts the moving comb fingers **208** to the fixed comb fingers **210**, which exert a torque on the mirror **204** and cause the mirror **204** to rotate about an axis **212**.

The capacitive coupling between the moving comb fingers **208** and the stationary comb fingers **210** can be measured in order to monitor the angle of the mirror **204**. Since the capacitance is fairly large, known methods can be employed to measure the capacitance with a high degree of accuracy. Similarly, comb-drives can be used for capacitive sensing only in a one-dimensional rotational actuator that employs another method of actuation (i.e. electrostatic gap-closing, magnetic).

U.S. Pat. No. 5,648,618 issued Jul. 15, 1997 to Neukermans et al., discloses a micromachined gimbaled actuator. An outer silicon frame oscillates around a first pair of bar shaped hinges by electrostatic or magnetic force. One end of each hinge of the first pair of hinges attaches to an inner frame, which attaches to a fixed inner post by a second pair of bar shaped torsion hinges positioned at right angles to the first set of hinges. The first and second pairs of bar shaped torsion hinges are made of single crystal silicon. First and second four-point piezoresistive strain sensors are built in the first and second pair of hinges for measuring the torsion displacement of the hinges. This apparatus does not possess several of the advantages gained by using comb-drive actuators and sensors, including linear behavior, low-voltage operation, and integration of the actuator and sensor in one structure. Furthermore, previous gimbaled structures have only employed lateral comb-drive actuators for in-plane motion.

There is a need, therefore, for an improved two-dimensional gimbaled scanner with out-of-plane rotational motion that provides linear drive and sense capabilities,